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The Position of the Sun's Axis as determined from photographs of the Sun from 1874 *to* 1912, *measured at the Royal Observatory, Greenwich.* (Second Paper.) By F. W. Dyson, M.A., LL.D., F.R.S., and E. W. Maunder.

1. In the earlier paper under this title communicated to the Royal Astronomical Society in May 1912, and appearing in the *Monthly Notices*, vol. lxxii. pp. 564–582, corrections were deduced to the assumed position of the Sun's axis as adopted in all the reductions of the measures of solar photographs made at Greenwich from 1874 up to the present time. This position was that determined by Carrington, viz.:

$$I = 7^\circ\ 15' \text{ and } N = 73^\circ\ 40' \text{ for } 1850{\cdot}0,$$

where I denotes the inclination of the Sun's equator to the ecliptic, and N the longitude on the ecliptic of its ascending node. If these require corrections ΔI and ΔN respectively, then, if

$$y = \Delta I \quad \text{and} \quad x = \Delta N \sin I,$$

it was shown that each spot-group observed for a sufficient period of time would yield a pair of equations for the determination of x and y of the following form:—

$$\left.\begin{aligned} x\cos\theta_1 - y\sin\theta_1 + l_1 = z \\ x\cos\theta_2 - y\sin\theta_2 + l_2 = z \end{aligned}\right\}$$

where θ_1, θ_2 are the longitudes of the spot-group reckoned on the ecliptic from the ascending node of the Sun's equator when the

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group is near the East and West limbs of the Sun respectively, l_1, l_2 are the corresponding observed latitudes, and z is the *true* latitude of the group. These by subtraction give

$$x(\cos\theta_1 - \cos\theta_2) - y(\sin\theta_1 - \sin\theta_2) = -(l_1 - l_2).$$

All groups observed satisfactorily for 8 or more consecutive days were employed, and the means of the observations of longitude and of latitude for 3, 4, or 5 consecutive days, according to the length of time that the particular spot-group was under observation, were taken to form θ and l. Thus the means of the observations for the first 3 days and for the last 3 days were taken with groups lasting for 8, 9, or 10 days; with 11-day groups the means were taken for 4 days; and with groups of longer duration for 5 days. In the present paper, for a reason to be noted later, means of 4 days were taken with the 12-day groups, as well as with those of 11 days.

2. The material discussed in the earlier paper can be considerably increased by treating in a similar manner the groups of spots that return to the visible hemisphere two or more times. A catalogue of these for the years 1874 to 1906 was compiled by Mrs. Walter Maunder and published as an Appendix to the Greenwich Photo-Heliographic Results for 1906; and this has been continued in the Photo-Heliographic Results for the subsequent years. Just as the series of equations employed in the earlier paper were formed from the determinations of latitude made near the East limb and West limb respectively, in the case of a spot transiting across the visible hemisphere, so a similar pair of equations can be formed in the case of a group passing across the invisible hemisphere, from the determinations of latitude made near the West limb before it passed out of sight, and near the East limb after it has returned within view. In the present paper, therefore, all cases of Recurrent groups, where the group was satisfactorily observed for three consecutive days before disappearance at the West limb, and again for three consecutive days after reappearance at the East limb, have been used to form equations for the determination of the error of position of the assumed axis, the mean of 3 days' observations being taken in each case. This corresponds to the position of the group on the second day from the limb, and allowing 15 or 16 days for the time during which the group is wholly or in part in the further hemisphere, the two positions involve an interval of 18 or 19 days, as compared with the intervals of from 5 to 9 days given by the groups observed for 8 or more days in the nearer hemisphere. This longer interval implies that the Recurrent groups will be more strongly affected by systematic errors due to steady proper motion on the part of the spot-groups. But errors of orientation, on the other hand, will affect the equations derived from the Recurrent groups only to the same general extent as those derived from groups observed in the course of a single apparition.

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The following is an example of the treatment of a Recurrent group:—

TABLE XV.

No. of Group.	Date.	Longitude of Sun from Node.	Longitude of Spot from Central Meridian.		Latitude of Spot.	
	1911. d		°		°	
6944	Apr. 23·386	...	−71·4		−7·1	
	24·433	...	−57·2		−6·7	
	25·113	...	−48·3		−6·8	
	26·425	...	−30·8		−6·3	
	27·611	...	−15·2		−6·0	
	28·528	...	− 2·8		−5·8	
	29·396	...	+ 8·7		−5·8	
	30·539	...	+24·1		−5·8	
	May 1·306	...	+34·3		−5·7	
	2·525	147°·5	+50·8	+62°·4	−5·8	−5°·73
	3·307		+61·4		−5·7	
	4·306		+75·1		−5·7	
Returning as						
6950	May 20·086	164°·8	−73·9	−57°·6	−6·7	−6°·50
	21·490		−54·9		−6·5	
	22·305		−44·1		−6·3	
	23·338	...	−30·8		−7·5	

Therefore, for the mean of the days May 2 to May 4 the longitude of the spot from the node = 147°·5 + 62°·4, or = 209°·9, and for the days May 20 to May 22 = 164°·8 − 57°·6, or = 107°·2; a difference of 102°·7 for an interval of 18 days. This gives the equations

$$0{\cdot}98\{x\cos 209^\circ{\cdot}9 - y\sin 209^\circ{\cdot}9\} - 5^\circ{\cdot}73 = +z$$

$$0{\cdot}98\{x\cos 107^\circ{\cdot}2 - y\sin 107^\circ{\cdot}2\} - 6^\circ{\cdot}50 = +z$$

giving by subtraction

$$-0{\cdot}56x + 1{\cdot}43y = -0^\circ{\cdot}77.$$

In this way the Recurrent groups yield a series of equations for the determination of x and y similar to those derived from the treatment of groups observed continuously in the course of the same apparition, as in the earlier paper.

The coefficients of x and y are, on the average, about as large as in the equations of the first paper, but the longer interval increases the effect of the proper motion of the spots, which, in these equations as in those considered before, is treated as accidental error.

3. A more important source of information is supplied by the observations of latitude made when a group of sun-spots is near

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the Central Meridian of the disc. For the method described in the earlier paper, *Monthly Notices*, vol. lxxii. pp. 572 to 578, proceeds on the assumption that the difference in the apparent latitude of a spot-group near the East and West limbs may be treated as an accidental error except so far as it arises from an error in the position of the Sun's axis. The proper motion of each group is treated as an accidental error, and contributes the largest part of these differences in the apparent latitude, the quantities on the right-hand side of the equations, as in Table VIII. on p. 576.

But if the proper motion of a group of spots is uniform during its motion across the disc, an equation obtained by comparing the apparent latitude of a group in the middle of its course across the visible hemisphere, with the mean of the apparent latitudes when it is nearer the limb, will be free from the error introduced by such motion. Thus in the example given in Table VII. (p. 575 of the earlier paper), and reproduced below in Table XVI., the

TABLE XVI.

Spot-Group 2496.

Date.		Longitude of Central Meridian from Node.	Longitude of Spot from Central Meridian.		Latitude of Spot.	
1892	d		°		°	
Apr.	27·52	145°·4	−81·2	−58°·0	−23·8	−24°·16
	28·43		−71·8		−23·9	
	29·40		−58·8		−24·3	
	30·41		−45·8		−24·4	
May	1·42		−32·4		−24·4	
	2·23	149°·8	−21·9	− 1°·5	−24·3	−24°·92
	3·40		− 6·4		−24·7	
	4·21		+ 3·8		−25·1	
	5·35		+18·6		−25·6	
	6·40	154°·1	+31·6	+55°·9	−25·2	−24°·56
	7·42		+44·1		−25·1	
	8·50		+56·6		−24·3	
	9·43		+67·7		−24·3	
	10·41		+79·7		−23·9	

equation derived from the mean of the first five days when the group was near the East Limb is

$$+0{\cdot}05x - 0{\cdot}94y - 24^\circ{\cdot}16 = z \quad . \quad . \quad . \quad (\alpha)$$

Similarly the last five days when the group was near the West Limb give

$$-0{\cdot}81x + 0{\cdot}47y - 24{\cdot}56 = z \quad . \quad . \quad . \quad (\beta)$$

The four middle days of observation when the group was near the Central Meridian would in like manner lead to the equation

$$-0{\cdot}82x - 0{\cdot}50y - 24{\cdot}92 = z \quad . \quad . \quad . \quad (\gamma)$$

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In the earlier paper the equation

$$+0{\cdot}86x - 1{\cdot}41y = -0^\circ{\cdot}40 \quad . \quad . \quad . \quad (\delta)$$

obtained by subtracting equation (β) from equation (α) was formed. Subtracting (γ) from the mean of (α) and (β) we find

$$+0{\cdot}44x + 0{\cdot}26y = -0^\circ{\cdot}56 \quad . \quad . \quad . \quad (\epsilon)$$

The smallness of the coefficients of x and y in the equation (ϵ) as compared with those of the equation (δ) would make it of small weight, if the right-hand sides of the two equations arose entirely from errors of measurement and other errors of purely accidental character. But the equation (ϵ) has two advantages over the equation (δ). The orientation error of the photograph is entirely eliminated. This is important, as the same orientation error might persist for a series of spot-groups which occurred at the same time of the year. More important than this, the proper motion of each spot, so far as it is linear, is eliminated. In consequence of this, the right-hand sides of the equations similar to (ϵ), which for the sake of brevity will be alluded to hereafter as Central equations, have a much smaller accidental error than those similar to equation (δ), which will be termed Limb equations.

In the case, therefore, of all groups observed for 11 or more consecutive days, a second equation has been formed by subtracting the equation derived from the determinations of latitude made near the Central Meridian from the mean of the two equations given by those made near the two limbs respectively. Thus in a group observed for 11 consecutive days the first 4 and last 4 days were used to form the two Limb equations, the remaining 3 days, in the middle of the period of observation, to form the central equation. With groups observed for 12 days the 4 middle days were used for the Central equation; this left 4 days for each of the Limb equations, and necessitated the re-computation of the 12-day groups; for in the earlier paper, the mean of 5 days' observations had been taken for these groups at each limb. With groups of either 13 or 14 days' duration, the first 5 days and last 5 days gave the Limb equations, as in the earlier paper, and the remaining 3 or 4 days, as the case might be, afforded the Central equation.

The employment of observations made near the Central Meridian was not contemplated when the discussion was first undertaken, but it was perceived in the course of the work that such observations could yield information of value. Had they been used from the first, the labour involved would have been greatly lessened, and the method of reduction made more uniform by forming the Limb equations in all cases by taking the means of 3 observations at each end of the period of the visibility of a group, and deriving the Central equations from the mean of the remaining days. The weight of the equations would have been slightly greater if this procedure had been adopted.

In this connection a mistake in the earlier paper should be pointed out. On p. 573 of vol. lxxii. the sentence at the top of

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the page should read:—"Thus y is obtained with a probable error of $\frac{\epsilon}{\sqrt{7}} = 0{\cdot}38\epsilon$, but x, from the way in which it is involved with z, with the much greater probable error, $0{\cdot}8\epsilon$. Thus as regards the position of the Sun's axis, four-fifths of the weight is concentrated in one of the normal equations, viz. that of y."

4. In Table XVII., which follows, are given the means of the quantities (irrespective of sign) on the right-hand sides of the equations formed in the three foregoing methods; *i.e.* from observations of spot-groups made near the Limbs only, from those in which observations made near the Centre were also used, and from Recurrent groups. As the quantities x and y to be determined from these equations of condition are very small, Table XVII. practically gives the mean discordances, and indicates the weights with which the separate groups should be combined. The first column indicates the class of observations concerned, the second

TABLE XVII.

Class of Observations.	Duration of Spot-groups.	No. of Groups.	Mean Discordances.	Means.
Limbs	8 days	327	±0°·562	
	9 "	288	0·670	
	10 "	293	0·734	
	11 "	313	0·704	
	12 "	524	0·645	
	13 "	434	0·623	
	14 "	33	0·596	
				±0·648
Central	11 days	313	±0·278	
	12 "	524	0·262	
	13 "	434	0·246	
	14 "	33	0·264	
				±0·262
Recurrent Groups		738	±0·971	
				±0·971

the length of time that the spot-groups were under observation, the third the total number of groups employed, and the fourth the mean discordances.

In the earlier paper the Limb groups were weighted according to the number of observations used in forming the mean longitudes and latitudes. Thus as 3 observations were taken together for the spot-groups of 8, 9, and 10 days' duration, all these were given the weight 3; the 11-day groups were given the weight 4, as the means were taken from 4 observations, and the weight 5 was given to spot-groups of 12, 13, and 14 days' duration. In the present paper the spot-groups of different duration, when only the Limb observations have been used, have been combined together with equal weights for each spot-group, since Table XVII.

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shows that they are approximately of the same weight. The same applies also to the different durations when the Centre observations have been also used. The mean discordances of the residuals given by the three different methods are

$$\pm 0^\circ\cdot 648\,; \quad \pm 0^\circ\cdot 262\,; \quad \pm 0^\circ\cdot 971\,;$$

the relative weights are

$$2\cdot 38 \;:\; 14\cdot 57 \;:\; 1\cdot 06,$$

or approximately as

$$2 \;:\; 12 \;:\; 1.$$

These weights have been adopted in combining the equations resulting from the different methods in order to give the combined mean results in Table XIX.

5. Table XVIII. gives the numbers of groups of sun-spots of each kind used in forming the various equations. Those given in the ninth column, "Total observed at Limb," correspond to those given in the third column of Table XII. in the earlier paper, but the observations of 1912 have been included, and those of 1905 have been completely revised. In four cases, a spot-group observed at the turn of the year has been, more correctly, included with the year in which it passed the Central Meridian, instead of that in which it was first observed.

Table XIX. gives values for x and y obtained by combining the equations from the different spot-groups year by year, except for years near the sun-spot minima, when three or four years are taken together. The results are given, first for each of the three methods separately, and finally for the three combined. The second and sixth columns, headed "Limb," correspond therefore to the fifth and sixth columns of Table XII. The discordances from the earlier paper are due to the removal of the weighting in favour of the groups of longer duration, and to the change in the number of observations used in forming the means for the 12-day groups, much the most numerous of the seven classes.

The equations have also been combined together, not only for the separate years, for the three completed sun-spot cycles, and for the entire period, but also according to the phase of the cycle. The years 1881–2, 1892–3, and 1904–5 were allotted to the Increasing phase; 1883, 1894–5, and 1906–7 to Maximum; 1884–5, 1896–7, and 1908–9 to the Decreasing phase, and the remaining 22 years to Minimum.

An examination of Table XIX. shows that—

(i) The corrections to the adopted position of the Sun's axis, as indicated by the entire material collected, are very small; viz. $\Delta I = -4'\cdot 5$, $\Delta N \sin I = +0'\cdot 9$.

(ii) The agreement between the results of the three methods is fairly close.

(iii) There are wide discordances between the results for different individual years, the spots observed near the Limbs giving the smallest range, and the Recurrent groups the widest, as would

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TABLE XVIII.

Numbers of Groups of Sun-spots employed.

Year.	Groups observed consecutively for							Total observed at		Recurrent Groups.	Total No. of Equations.
	8^d	9^d	10^d	11^d	12^d	13^d	14^d	Limb.	Centre.		
1874–1877	12	14	12	17	12	8	0	75	37	26	138
1878–1880	7	5	5	13	16	5	0	51	34	19	104
1881	17	12	6	11	17	13	1	77	42	30	149
2	11	12	12	15	20	13	2	85	50	38	173
3	18	13	20	12	27	22	1	113	62	37	212
4	15	18	14	16	30	21	0	114	67	47	228
5	4	7	8	13	30	24	0	86	67	34	187
1886–1888	12	3	11	14	20	19	2	81	55	27	163
1889–1891	12	10	9	13	15	24	3	86	55	34	175
1892	12	20	18	19	31	29	3	132	82	43	257
3	24	29	20	25	42	32	2	174	101	62	337
4	28	21	17	14	35	38	4	157	91	47	295
5	17	14	17	17	30	26	1	122	74	33	229
6	12	9	12	8	14	10	1	66	33	17	116
7	6	5	4	9	12	15	0	51	36	19	106
1898–1900	13	9	12	11	19	13	1	78	44	19	141
1901–1903	7	8	6	10	7	13	0	51	30	12	93
1904	18	12	5	8	17	14	0	74	39	16	129
5	11	12	22	9	18	6	1	79	34	27	140
6	14	19	13	11	21	17	7	102	56	32	190
7	22	10	13	17	28	25	1	116	71	41	228
8	13	11	21	14	18	16	2	95	50	28	173
9	15	9	5	8	24	25	1	87	58	34	179
1910–1912	7	6	11	9	21	6	0	60	36	16	112
1878–1888	84	70	76	94	160	117	6	607	377	232	1216
1889–1900	124	117	109	116	198	187	15	866	516	274	1656
1901–1912	107	87	96	86	154	122	12	664	374	206	1244
1878–1912	315	274	281	296	512	426	33	2137	1267	712	4116
1874–1912	327	288	293	313	524	434	33	2212	1304	738	4254
Minimum	70	55	66	87	110	88	6	482	291	153	926
Increasing	93	97	83	87	145	107	9	621	348	216	1185
Maximum	99	77	80	71	141	128	14	610	354	190	1154
Decreasing	65	59	64	68	128	111	4	499	311	179	989

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Table XIX.

Corrections to the Adopted Position of the Sun's Axis.

Period.	*x.*				*y.*			
	Limb.	Centre.	Recurrent.	Combined.	Limb.	Centre.	Recurrent.	Combined.
1874–1877	− 10′·0	− 1′·0	− 16′·7	− 8′·4	+ 14′·4	− 16′·6	+ 0′·0	+ 7′·0
1878–1880	− 0·8	− 20·9	− 11·5	− 5·9	− 3·4	− 7·7	− 7·2	− 7·6
1881	+ 1·3	− 31·8	+ 23·3	− 0·9	− 9·0	+ 13·5	+ 1·9	− 3·7
2	+ 9·9	− 1·3	+ 5·3	+ 7·6	− 8·3	− 0·1	+ 2·5	− 5·2
3	− 0·6	+ 12·0	− 28·8	− 0·2	− 5·3	− 1·6	− 5·2	− 4·4
4	+ 11·5	− 1·7	+ 15·9	+ 9·7	+ 0·5	− 5·7	+ 12·7	+ 0·6
5	+ 14·1	− 8·3	+ 21·5	+ 9·8	− 7·6	+ 0·1	− 12·6	− 7·3
1886-1888	− 3·7	− 5·6	+ 4·1	− 2·5	− 7·5	− 2·4	− 18·9	− 7·2
1889–1891	− 3·0	+ 7·9	+ 22·0	+ 2·8	− 4·0	− 20·7	− 21·7	− 9·6
1892	+ 5·9	+ 7·4	− 2·6	+ 5·7	− 8·7	− 9·5	+ 2·9	− 7·7
3	+ 1·5	+ 1·9	− 17·7	− 1·0	− 9·9	− 4·2	− 1·2	− 7·5
4	+ 2·2	− 0·6	− 10·4	+ 0·3	+ 0·8	− 2·9	+ 2·0	+ 0·0
5	+ 5·5	− 0·2	+ 11·8	+ 5·0	− 9·8	− 4·5	− 3·2	− 8·1
6	− 3·8	+ 10·0	− 9·5	− 2·8	− 11·7	+ 5·8	+ 8·7	− 6·9
7	+ 10·2	− 5·4	+ 9·7	+ 6·9	− 12·7	+ 3·9	− 11·9	− 6·9
1898–1900	− 3·3	− 10·0	− 9·7	− 5·1	− 12·7	− 6·9	− 12·5	− 11·2
1901–1903	+ 5·3	+ 7·1	+ 28·0	+ 8·4	− 3·1	+ 11·6	+ 4·1	− 0·2
1904	+ 1·0	− 16·7	+ 10·1	− 2·4	+ 3·3	− 2·7	+ 20·2	+ 3·7
5	+ 2·4	+ 8·4	+ 2·0	+ 2·0	− 4·1	+ 9·5	− 17·7	− 3·6
6	− 5·9	+ 14·5	+ 0·6	− 1·0	− 5·3	− 8·9	− 23·2	− 9·2
7	+ 0·3	− 8·6	− 2·2	− 1·1	+ 8·7	− 10·9	− 20·8	− 0·3
8	− 8·5	− 1·3	+ 4·4	− 5·3	− 5·9	+ 11·3	− 16·3	− 3·1
9	− 10·2	+ 1·4	− 2·0	− 6·4	+ 9·2	− 19·9	− 22·2	− 2·8
1910–1912	− 0·4	+ 7·5	+ 6·6	+ 1·8	− 3·9	+ 6·1	− 3·9	− 1·2
1878–1888	+ 5·5	− 5·3	+ 5·3	+ 3·4	− 5·5	− 1·2	− 4·7	− 4·6
1889–1900	+ 2·1	+ 1·7	− 2·2	+ 1·6	− 7·6	− 5·6	− 3·0	− 6·7
1901–1912	− 2·8	+ 1·9	+ 0·5	− 1·4	− 0·0	− 3·5	− 14·3	− 2·6
1878–1912	+ 1·5	− 0·2	+ 1·0	+ 1·2	− 4·8	− 3·8	− 7·1	− 4·8
1874–1912	+ 1·2	− 0·2	+ 0·4	+ 0·9	− 4·2	− 4·1	− 6·9	− 4·5
Minimum	− 2·5	− 0·3	+ 0·5	− 1·7	− 3·3	− 6·4	− 12·9	− 5·0
Increasing	+ 3·7	− 2·3	− 1·3	+ 1·9	− 7·1	− 1·6	− 0·4	− 5·1
Maximum	+ 0·7	+ 3·5	− 5·4	+ 0·6	− 2·6	− 5·5	− 9·4	− 4·2
Decreasing	+ 2·3	− 1·3	+ 7·7	+ 2·3	− 3·3	− 3·2	− 7·3	− 3·7

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naturally follow from the relative numbers of observations available for the three methods.

(iv) The irregular way in which these discordances are distributed indicates that they are due to irregular proper motions of spot-groups, large as compared with the errors in the adopted position of the axis.

(v) There is no sufficient evidence of any regular progressive motion of the axis during the period of observation.

(vi) Nor of any motion periodic with the sun-spot cycle.

6. To these conclusions may be added :—

(vii) There is no strongly marked evidence of any progressive difference in the determined position of the axis, depending on the latitude of the spot-groups from whence it is derived.

This appears from Table XX., the figures in which do indeed suggest a slightly larger correction to the inclination of the axis as derived from spots north of the equator than from those south of it; but the difference from the mean value is less than 2′. The difference is a little more marked if only spots with latitudes greater than 10° are considered, but it still remains under 3′. This range of difference is the same as that shown by the three complete sun-spot cycles, and by the four different phases of the cycle. Within this range, therefore, the position of the axis does not differ for different cycles, for different phases of the cycle, or for different zones.

Table XX.

Corrections to the Adopted Position of the Sun's Axis as determined from Spot-groups in Different Zones.

Zone.	*x.*				*y.*			
	Limb.	Central.	Re-current.	Com-bined.	Limb.	Central.	Re-current.	Com-bined.
°	′	′	′	′	′	′	′	′
Above +18	−0·2	+1·1	+ 1·7	+0·3	−5·8	−2·2	− 9·8	−5·6
+18+14	+2·1	−4·9	+13·3	+1·6	−8·5	−7·6	− 8·3	−8·2
+14+10	+4·5	−3·3	+ 4·0	+3·0	−3·9	−8·6	−17·5	−6·5
+10+ 6	−3·3	+0·3	−13·6	−3·8	−3·1	−7·6	− 6·3	−4·6
+ 6+ 0	+8·8	−1·8	+11·7	+7·3	−7·6	−3·7	− 4·0	−6·1
− 0− 6	−4·7	+0·9	− 3·1	−3·6	+6·7	−9·1	− 0·8	+2·1
− 6−10	+0·9	+5·8	+ 7·7	+2·6	−8·6	−1·3	− 4·1	−6·3
−10−14	+3·1	−9·7	− 8·3	−0·7	−2·7	+0·1	− 6·0	−2·3
−14−18	−1·6	+9·7	+ 0·1	+1·1	−3·9	+0·3	− 3·5	−3·0
Below −18	+3·7	+0·1	− 7·5	+1·6	−2·4	−5·3	− 2·2	−3·0
Above +10	+2·4	−2·4	+ 5·7	+1·7	−5·8	−6·5	−12·5	−6·7
+10−10	−0·4	+1·9	+ 0·3	+0·1	−3·8	−5·1	− 4·5	−4·2
Below −10	+1·7	+0·2	− 5·0	+0·7	−3·1	−1·3	− 3·6	−2·8
North	+1·8	−1·8	+ 2·8	+1·1	−5·4	−6·4	−11·3	−6·2
South	+0·8	+1·2	− 1·9	+0·6	−3·1	−2·2	− 3·5	−3·0
All spots	+1·2	−0·2	+ 0·4	+0·9	−4·2	−4·1	− 6·9	−4·5

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7. Spot-groups observed for 11 or more consecutive days are seen practically for a complete transit, from one limb to the other, and observations of them must be, in the mean, symmetrical with regard to the Central Meridian. This is not the case with groups of shorter duration, with the 8-, 9-, and 10-day groups. Of these some, which may be termed Eastern groups, are seen from the East limb onwards, but disappear before reaching the West limb; others, which may be termed Western groups, make their first appearance some distance from the East limb, but are followed up to the West limb; while others again are Central groups, forming and disappearing within the visible hemisphere. Since there is a systematic preponderance of the first of these three classes over the others, and of Central groups over the Western, the groups of short duration are not, on the whole, distributed quite symmetrically with respect to the Central Meridian, and hence the data they supply for the correction of the Sun's axis may be open to systematic error. The following table, however, does not indicate with certainty any correction due on this account. It is true that, when the groups of all the three durations are taken together, there appears to be a slight progression in the values of x and y, as we pass from the Eastern to the Central, and thence to the Western groups; but the discordances between the groups of different durations taken separately are too large to permit much significance to be attached to this circumstance.

TABLE XXI.

Class of Spot-group.	Duration of Spot-group.	x.	y.
Eastern	8 days	+ 5′·7	− 0′·4
	9 „	− 4·9	− 1·1
	10 „	+ 4·7	− 9·0
	8–10 „	+ 2·3	− 4·6
Central	8 days	+ 1·7	− 6·3
	9 „	− 0·3	− 0·7
	10 „	+ 1·6	+ 3·8
	8–10 „	+ 0·8	− 0·3
Western	8 days	+ 4·6	+ 11·3
	9 „	− 11·4	− 2·1
	10 „	− 0·7	− 3·7
	8–10 „	− 1·8	+ 1·0
All positions	8 days	+ 4·3	+ 0·8
	9 „	− 4·6	− 1·2
	10 „	+ 2·4	− 3·9
	8–10 „	+ 0·8	− 1·8

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Table XXII.

Numbers of Observations.

Zone.	Limb.				Recurrent Groups.			
	Minimum.	Increasing.	Maximum.	Decreasing.	Minimum.	Increasing.	Maximum.	Decreasing.
Above +18°	68	113	45	6	33	38	17	...
+18 +14	33	74	60	24	13	29	15	8
+14 +10	35	97	85	68	7	32	36	21
+10 + 6	44	42	71	60	7	10	19	23
+ 6 + 0	19	10	31	31	10	4	7	9
− 0 − 6	43	10	28	49	10	...	5	24
− 6 −10	74	29	64	79	25	11	17	30
−10 −14	68	53	79	81	22	16	25	28
−14 −18	36	75	85	74	14	31	26	28
Below −18	62	118	62	27	12	45	23	8
Above +10	136	284	190	98	53	99	68	29
+10 −10	180	91	194	219	52	25	48	86
Below −10	166	246	226	182	48	92	74	64
North	199	336	292	189	70	113	94	61
South	283	285	318	310	83	103	96	118
All spots	482	621	610	499	153	216	190	179

Zone.	1874 to 1888.	1889 to 1900.	1901 to 1912.	1874 to 1912.	1874 to 1888.	1889 to 1900.	1901 to 1912.	1874 to 1912.
Above +18°	71	102	59	232	34	37	17	88
+18 +14	53	86	52	191	21	26	18	65
+14 +10	84	107	94	285	24	38	34	96
+10 + 6	62	66	89	217	22	14	23	59
+ 6 + 0	25	41	25	91	10	11	9	30
− 0 − 6	45	42	43	130	14	11	14	39
− 6 −10	86	95	65	246	36	28	19	83
−10 −14	102	105	74	281	40	33	18	91
−14 −18	75	97	98	270	31	31	37	99
Below −18	79	125	65	269	26	45	17	88
Above +10	208	295	205	708	79	101	69	249
+10 −10	218	244	222	684	82	64	65	211
Below −10	256	327	237	820	97	109	72	278
North	295	402	319	1016	111	126	101	338
South	387	464	345	1196	147	148	105	400
All spots	682	866	664	2212	258	274	206	738

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TABLE XXIII.

Mean Discordances in Latitude.

Zone.	Limb.				Recurrent Groups.			
	Minimum.	Increasing.	Maximum.	Decreasing.	Minimum.	Increasing.	Maximum.	Decreasing.
Above +18°	+5·5′	+3·1′	+5·1′	−8·4′	+5·2′	+16·0′	+4·2′	...′
+18 +14	−11·1	+0·3	−3·8	−8·1	−12·4	−9·7	+9·2	+13·0
+14 +10	−4·1	−10·8	−6·6	−3·5	+18·2	−28·9	−4·3	+3·2
+10 +6	+1·0	−4·1	−1·8	−9·7	−53·4	−6·8	−21·5	+16·3
+6 +0	−1·1	−14·9	+1·4	−12·7	+5·3	−74·4	−14·0	−2·4
−0 −6	+0·7	+9·5	+4·4	+8·0	+16·6	...	−30·5	+25·8
−6 −10	−1·7	+9·1	−6·7	+5·6	−5·2	+41·7	+30·1	−5·8
−10 −14	−1·7	−4·2	−2·8	−1·1	−4·0	−1·2	+2·0	+12·2
−14 −18	+13·6	+1·6	−5·6	+8·9	+35·9	+2·9	−21·1	+21·4
Below −18	−4·9	−12·8	+8·3	−2·2	−4·0	+1·3	−10·4	−40·9
Above +10	−1·0	−2·4	−2·9	−4·9	+2·6	−6·1	+0·8	+5·9
+10 −10	−0·4	+0·4	−2·0	−0·6	−5·5	+3·8	−3·1	+9·3
Below −10	+0·4	−6·5	−0·8	+2·8	+7·7	+1·4	−10·0	+9·6
North	−0·5	−3·0	−2·2	−7·7	−2·6	−8·5	−4·8	+8·6
South	−0·1	−4·4	−1·6	+4·3	+4·9	+5·7	−4·0	+9·0
All spots	−0·3	−3·6	−1·9	−0·2	+1·4	−1·7	−4·4	+8·9

Zone.	1874 to 1888.	1889 to 1900.	1901 to 1912.	1874 to 1912.	1874 to 1888.	1889 to 1900.	1901 to 1912.	1874 to 1912.
Above +18°	+19·7′	−3·1′	−2·9′	+3·9′	−1·0′	+16·3′	+16·6′	+9·7′
+18 +14	+0·0	−8·6	−0·4	−4·0	+0·1	−15·1	+10·6	−3·1
+14 +10	+1·3	−15·5	−4·7	−7·0	+10·1	−0·2	−32·9	−9·2
+10 +6	−0·2	−12·8	+0·2	−3·8	−29·5	−3·7	+9·8	−8·0
+6 +0	−5·0	−8·1	−2·5	−5·7	−13·7	−10·6	−12·1	−12·1
−0 −6	+0·1	+3·4	+11·6	+5·0	+31·2	−10·3	+21·1	+16·3
−6 −10	+11·2	−5·0	−5·0	+0·6	−1·3	+23·9	+2·3	+8·0
−10 −14	+2·6	−10·7	+3·0	−2·2	−14·8	+17·6	+16·3	+3·1
−14 −18	+10·8	−10·9	+10·6	+2·9	+32·6	+12·5	−20·4	+6·5
Below −18	+6·4	−10·3	−8·9	−5·0	−20·1	+5·7	−17·2	−6·4
Above +10	+7·3	−9·2	−3·1	−2·6	+2·7	+2·0	−9·4	−1·0
+10 −10	+3·8	−6·2	+0·6	−0·8	−4·7	+6·1	+7·0	+2·2
Below −10	+6·2	−10·6	+2·9	−1·4	−1·1	+11·2	−10·4	+1·3
North	+4·6	−9·7	−2·1	−3·2	−5·2	+0·2	−5·3	−3·2
South	+6·5	−8·2	+2·5	−0·4	+2·0	+12·1	−4·0	+4·1
All spots	+5·7	−8·9	+0·3	−1·4	−1·1	+6·6	−4·6	+0·8

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The foregoing comparison as to the effect on the determination of the Sun's axis of the mean position of spot-groups of short duration—whether near the East limb, the Central Meridian, or the West limb respectively—was made soon after the completion of the earlier paper, and the same material was employed as for that. The result of the comparison appearing to be of a negative character, it did not appear worth while to go through the computations again in order to make the small alterations which the use of the very slightly fuller material of the present paper would introduce.

8. It will be remembered that in Carrington's determination of the position of the Sun's axis he found an apparent tendency of spots to move northward at the rate of 90″ in the time during which the Sun rotates through 30° (*Observations of the Spots on the Sun*, p. 242). This he regarded as "a fictitious and non-real result," but it seemed worth while to inquire if the Greenwich measures confirmed it or otherwise; and in particular—having in view the well-known change in the latitude-distribution of sun-spots with the progress of the solar cycle—whether any tendency to move towards the equator or from it, characterised the spots of any particular zone, or at any particular phase of the sun-spot cycle. For this purpose the observed differences of latitude, *i.e.* the quantities on the right-hand side of the equations of condition, in the cases of the Limb equations and of those from the Recurrent groups, have been grouped in ten zones, according to the latitude of the spot-group concerned. The Central equations having been cleared, by the way in which they have been formed, from the effects of a steady uniform drift in any one given direction, have not been treated in this manner.

Tables XXII. and XXIII. give respectively the numbers of observations, and the mean discordances in latitude for the different zones, both for the three cycles of the sun-spot activity over which the observations extend, and for the several phases of the progress of the cycle. As in the earlier paper, motion towards the N. Pole is considered positive.

It will be seen that the observations do not establish the reality of a common drift of the sun-spots to the extent that the figures derived by Carrington might be taken to indicate. The average interval corresponding to the mean discordances from the Limb equations is 7 days, in which time the Sun rotates through 100°; and the average interval for the Recurrent groups is 18 days, or more than 2½ times as long. A movement of 1′·5 in latitude for a rotation of 30° would show as 5′ from the Limb equations, and as 13′ from those given by the Recurrent groups. But instead of a northward movement of this amount the final result from the Recurrent groups is almost *nil*, and from the Limb spots is a very small movement southward, while the individual figures given in the tables show a wide range. In other words, though in limited areas of the Sun's surface groups of spots are often observed to have a "set" in one direction or the other that

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may last for some time, these tend in the long run to balance one another.

For the Limb equations, the two columns "1874 to 1888" and "1889 to 1900" are in somewhat striking contrast, and suggest that the photographs of both periods were generally affected by a sensible orientation error, but of different signs in the two periods. If this were the case, the Recurrent groups should reverse the effect, for orientation error will affect the differences in latitude from the Recurrent groups to the same amount as it will those from the spot-groups observed near the Limb, but with the opposite sign. The Recurrent groups are exposed to accidental errors of too large an amount, and the numbers of groups available in each zone in the separate periods are too few for the actual figures to have much significance; but so far as they go, when taken together with those from the Limb equations, they confirm the conclusion that small outstanding orientation errors gave a slight apparent northward motion to the spots in their transit across the disc in the period 1874 to 1888, but a southward motion in the period 1889 to 1900. The third period, 1901 to 1912, appears to have been practically free from any general error of this nature.

But though there is no satisfactory indication of any general drift of all spots in the same direction, the column "1874 to 1912" does suggest a slight tendency for spots in the outer zones of either hemisphere to move towards the pole of that hemisphere, while the spots in all other zones tend on the whole to move towards the equator. This appears to be shown both by the spots near the Limb and by the Recurrent groups.

9. In conclusion, the results obtained may be summarised:—

(1) Small corrections to Carrington's elements appear to be indicated; viz.

$$\Delta I = -4'{\cdot}5 \qquad \Delta N \sin I = +0'{\cdot}9,$$

giving the true position of the solar equator, for the epoch 1850·0, as

$$I = 7^\circ\ 10'{\cdot}5 \qquad N = 73^\circ\ 46'{\cdot}8.$$

(2) The final corrections, as deduced by the "Limb" and "Central" methods respectively, are in close accord; showing that they are substantially free from systematic errors due either to defective orientation of the photographs, or to a general drift of the spot-groups.

(3) The discordances between the corrections deduced from short periods, such as a single year, or from spot-groups in restricted zones, are due to the large proper motions of individual groups. These last show a certain tendency to run into sets, but do not persist over long periods of time.

(4) A slight general tendency is suggested for high-latitude spots in either hemisphere to move away from the equator, but for those in lower latitudes to move towards it.

Royal Observatory, Greenwich:
1913 *June* 13.

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Mean Areas and Heliographic Latitudes of Sun-spots in the Year 1912.

(*Communicated by the Astronomer Royal.*)

The results here given are in continuation of those printed in the *Monthly Notices*, vol. lxxiii. p. 47, and are deduced from the measurements of photographs taken at the Royal Observatories of Greenwich and of the Cape, and in India at the Kodaikánal Observatory and at Dehra Dûn, North-West Provinces.

Table I. gives the mean daily area of umbræ, whole spots, and faculæ for each synodic rotation of the Sun in the year 1912, and Table II. gives the same particulars for each of the entire years 1901 to 1912 inclusive. The areas are given in two forms: first, projected areas, that is to say, as seen and measured on the photographs, these being expressed as millionths of the Sun's apparent disc; and next, areas as corrected for foreshortening, the areas in this case being expressed in millionths of the Sun's visible hemisphere.

Table III. exhibits for each rotation in the year 1912 the mean daily area of the whole spots (corrected for foreshortening), and the mean heliographic latitude of the spotted areas for spots north and for spots south of the equator, together with the mean heliographic latitude of the entire spotted area and the mean distance from the equator of all spots; and Table IV. gives the same information for each year as a whole for the years 1901 to 1912 inclusive. Tables II. and IV. are thus in continuation of the similar tables for the years 1874 to 1888 on

Table I.

No. of Rotation.	Date of Commencement of each Rotation.		No. of Days on which Photographs were taken.	Mean of Daily Areas.					
				Projected.			Corrected for Foreshortening.		
				Umbræ.	Whole Spots.	Faculæ.	Umbræ.	Whole Spots.	Faculæ.
	1912.	d							
780	Jan.	13·42	27	0	0	221	0	0	232
781	Feb.	9·76	27	0	4	169	1	7	189
782	Mar.	8·09	27	16	88	158	11	59	172
783	Apr.	4·39	28	23	109	189	19	97	199
784	May	1·65	27	3	27	258	2	17	243
785	May	28·87	27	17	95	376	12	77	387
786	June	25·07	26	8	45	223	6	33	238
787	July	22·27	27	0	0	109	0	0	115
788	Aug.	18·50	28	4	24	182	3	16	191
789	Sept.	14·75	27	29	139	257	20	98	283
790	Oct.	12·03	27	0	1	187	0	1	195
791	Nov.	8·33	28	1	5	102	1	3	104
792	Dec.	5·64	27	27	143	204	18	96	201